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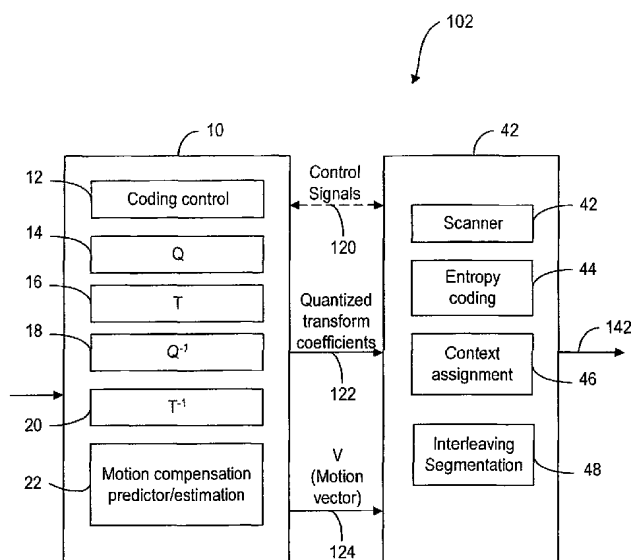
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(54) Title: CONTEXT-BASED ADAPTIVE VARIABLE LENGTH CODING FOR ADAPTIVE BLOCK TRANSFORMS



(57) Abstract: A method and system for coding an image using context-based adaptive VLC where transform coefficients are partitioned into blocks having a block dimension of $4n \times 4m$ (with n, m being positive integer equal to or greater than 1). Each block is scanned in a zigzag manner to produce an ordered vector of coefficients having a length of $16nm$. The ordered vector is sub-sampled in an interleaved manner to produce nxm sub-sampled sequences of transform coefficients prior to encoding the transform coefficients using an entropy encoder.

CONTEXT-BASED ADAPTIVE VARIABLE LENGTH CODING FOR ADAPTIVE BLOCK TRANSFORMS

5 Field of the Invention

The present invention is generally related to the field of video coding and compression and, more particularly, to a method and system for context-based adaptive variable length coding.

10 Background of the Invention

A typical video encoder partitions each frame of the original video sequence into contiguous rectangular regions called “blocks”. These blocks are encoded in “intra mode” (I-mode), or in “inter mode” (P-mode). For P-mode, the encoder first searches for a block similar to the one being encoded in a previously transmitted “reference frame”, denoted by
 15 F_{ref} . Searches are generally restricted to being no more than a certain spatial displacement from the block to be encoded. When the best match, or “prediction”, has been identified, it is expressed in the form of a two-dimensional (2D) motion vector $(\Delta x, \Delta y)$ where Δx is the horizontal and Δy is the vertical displacement. The motion vectors together with the reference frame are used to construct a predicted block F_{pred} :

20

$$F_{pred}(x,y) = F_{ref}(x+\Delta x, y+\Delta y)$$

The location of a pixel within the frame is denoted by (x, y) .

For blocks encoded in I-mode, the predicted block is formed using spatial prediction
 25 from previously encoded neighboring blocks within the same frame. For both I-mode and P-mode, the prediction error, i.e. the difference between the block being encoded and the predicted block, is represented as a set of weighted basis functions of some discrete transform. Transforms are typically performed on an 8x8 or 4x4 block basis. The weights – transform coefficients – are subsequently quantized. Quantization introduces loss of
 30 information, thus quantized coefficients have lower precision than the original ones.

Quantized transform coefficients and motion vectors are examples of “syntax elements”. These, plus some control information, form a complete coded representation of

the video sequence. Prior to transmission from the encoder to the decoder, all syntax elements are entropy coded, thereby further reducing the number of bits needed for their representation. Entropy coding is a lossless operation aimed at minimizing the number of bits required to represent transmitted or stored symbols (in our case syntax elements) by
5 utilizing properties of their distribution (some symbols occur more frequently than others).

One method of entropy coding employed by video coders is Variable Length Codes (VLC). A VLC codeword, which is a sequence of bits (0's and 1's), is assigned to each symbol. The VLC is constructed so that the codeword lengths correspond to how frequently the symbol represented by the codeword occurs, e.g. more frequently occurring symbols are
10 represented by shorter VLC codewords. Moreover, the VLC must be constructed so that the codewords are uniquely decodable, i.e., if the decoder receives a valid sequence of bits of a finite length, there must be only one possible sequence of input symbols that, when encoded, would have produced the received sequence of bits.

To correctly decode the bitstream, both encoder and decoder have to use the same set
15 of VLC codewords and the same assignment of symbols to them. As discussed earlier, to maximize the compression, the most frequently occurring symbols should be assigned the shortest VLC codewords. However, the frequency (probability) of different symbols is dependant upon the actual frame being encoded. In the case where a single set of VLC codewords, and a constant assignment of symbols to those codewords is used, it is likely that
20 the probability distribution of symbols within a given frame will differ from the probabilities assumed by the VLC, even though the average symbol probability across the entire sequence may not. Consequently, using a single set of VLC codewords and a single assignment of symbols to those codewords reduces coding efficiency.

To rectify this problem different methods of adaptation are used. One approach,
25 which offers reasonable computational complexity, and a good compression versus efficiency trade-off, and which is currently used in the state-of-the art video coders, is now described. For a set of symbols, a number of tables specifying VLC codewords (VLCs) are provided for the encoder and the decoder to use. The table selected to encode a particular symbol then depends on the information known both to the encoder and decoder, such as the type of the
30 coded block (I- or P- type block), the component (luma or chroma) being coded, or the

quantization parameter (QP) value. The performance depends on how well the parameters used to switch between the VLCs characterize the symbol statistics.

In the decoder, the block in the current frame is obtained by first constructing its prediction in the same manner as in the encoder, and by adding to the prediction the compressed prediction error. The compressed prediction error is found by weighting the transform basis functions using the quantized coefficients. The difference between the reconstructed frame and the original frame is called reconstruction error.

The compression ratio, i.e. the ratio of the number of bits used to represent original sequence and the compressed one, may be controlled by adjusting the value of the quantization parameter (QP) used when quantizing transform coefficients. The compression ratio also depends on the method of entropy coding employed.

Coefficients in a given block are ordered (scanned) using zigzag scanning, resulting in a one-dimensional ordered coefficient vector. An exemplary zigzag scan for a 4x4 block is shown in Figure 1.

Zigzag scanning presumes that, after applying 2 dimensional (2D) transform, the transform coefficients having most energy (i.e. higher value coefficients) correspond to low frequency transform functions and are located toward the top-left of the block as it is depicted in Figure 1. Thus, in a coefficient vector produced through zigzag scanning, the higher magnitude coefficients are most likely to appear toward the start of the vector. After quantization most of the low energy coefficients become equal to 0.

The vector of coefficients can be further processed so that each nonzero coefficient is represented by 2 values: a *run* (the number of consecutive zero coefficients proceeding a nonzero value in the vector), and a *level* (the coefficient's value).

CAVLC (Context-based Adaptive VLC) is the method of coding transform coefficients used in the JVT coder "Joint Final Committee Draft (JFCD) of Joint Video Specification (ITU-T Rec. H.264 | ISO/IEC 14496-10 AVC)". In summary, encoding a single 4x4 block using CAVLC involves five steps:

1. Encoding the total number of nonzero coefficients in the block, combined with the number of "trailing ones".

The number of trailing ones is defined as the number of coefficients with a magnitude of one that are encountered before a coefficient with magnitude greater than one is encountered when the coefficient vector is read in reverse order (i.e. 15, 14, 13, 12, 11, ...
5 in Figure 1). The VLC used to code this information is based upon a predicted number of nonzero coefficients, where the prediction is based on the number of nonzero coefficients in previously encoded neighboring blocks (upper and left blocks).

2. Encoding the sign of any trailing ones.

3. Encoding the *levels* (magnitudes) of nonzero coefficients other than the trailing ones.

4. Encoding the number of zero values in the coefficient vector before the last nonzero coefficient, i.e. the sum of all the “*runs*”. The VLC used when coding this value
15 depends upon the total number of nonzero coefficients in the block, since there is some relationship between these two values.

5. Encoding the *run* that occurs before each nonzero coefficient, starting from the last nonzero value in the coefficient vector.

The VLC used to encode a *run* value is selected based upon the sum of the *runs* from step (4), and the sum of the *runs* coded so far. For example, if a block has a “sum of *runs*” of 8, and the first *run* encoded is 6, then all remaining *runs* must be 0, 1, or 2. Because the possible *run* length becomes progressively shorter, more efficient VLC codes are selected to
25 minimize the number of bits required to represent the *run*.

A typical block-based video encoder is shown in Figure 2. As shown in Figure 1, the video server 100 comprises a front-end unit 10, which receives video signals 110 from a video source, and a video multiplex coder 40. Each frame of uncompressed video provided from the video source to the input 110 is received and processed macroblock-by-macroblock
30 in a raster-scan order. The front-end unit 10 comprises a coding control manager 12 to switch

between the I-mode and P-mode and to perform timing coordination with the multiplex coder 40 via control signals 120, a DCT (Discrete Cosine Transform) transformation module 16 and a quantizer 14 to provide quantized DCT coefficients. The quantized DCT coefficients 122 are conveyed to the multiplex coder 40. The front-end unit 10 also comprises an inverse quantizer 18 and an inverse transformation unit 20 to perform an inverse block-based discrete cosine transform (IDCT), and a motion compensation prediction and estimation module 22 to reduce the temporal redundancy in video sequences and to provide a prediction error frame for error prediction and compensation purposes. The motion estimation module 22 also provides a motion vector 124 for each macroblock to the multiplex coder 40. The multiplex coder 40 typically comprises a scanning module 42 to perform the zigzag scan for forming an order vector for each block of image data, an entropy coding module to designate non-zero quantized DCT coefficients with *run* and *level* parameters. The *run* and *level* values are further mapped to a sequence of bins, each of which is assigned to a so-called 'context' by a context assignment module 46. The contexts, along with the motion vector, is formatted into a bitstream 140. A context-based encoder is known in the art. Furthermore, it is possible that the transformation module 16 is a FFT (Fast Fourier Transform) module or DFT (Discrete Fourier Transform) module, and that DCT can be an approximation of a DCT.

A typical decoder is shown in Figure 3. As shown, a client 200 comprises a video multiplex decoder 60, which receives the encoded video bitstream 140 from the encoder 40. The decoder 60 also decodes an I-mode frame on a macroblock-by-macroblock basis. Based on the VLC codewords contained in the bitstream 140, a coefficient extractor module 62 in the decoder 60 recovers the *run* and *level* values, and then reconstructs an array of quantized DCT coefficients 162 for each block of the macroblock. The encoded motion vector information associated with the macroblock is extracted from the encoded video bitstream 140. The extracted motion vector 166, along with the reconstructed quantized DCT coefficients 162, is provided to a back-end unit 80. An inverse quantizer 84 inverse quantizes the quantized DCT coefficients 162 representing the prediction error information for each block of the macroblock provides the results to an inverse transformer 86. With the control information provided by a coding control manager 82, an array of reconstructed prediction

error values for each block of the macroblock is yielded in order to produce video signals
180.

Currently, video and still images are typically coded with help of a block-wise transformation to frequency domain. Such coding method is used in H.26L (or H.264-to-be)
5 standard by the Joint Video Team (JVT). In such a method, the image is first subdivided into blocks of 4x4 pixels in size and the blocks are transformed into a 4x4 matrix of transform coefficients. The coefficients are then arranged by scanning them along a zigzag path, wherein the low-frequency coefficients are placed first in the scan in order to form an ordered sequence of transform coefficients - a one-dimensional vector. A 4x4 transform coefficient
10 matrix of Figure 1 will result in a one-dimension array or a sequence of 1, 2, 5, 9, 6, 3, 4, 7, 10, 13, 14, 11, 8, 12, 15, 16. This is advantageous because the following step is to code the quantized values of the DCT coefficients by *run*-length coding, whereby the more probable *runs* are represented by short codes (Huffman coding or arithmetic coding). Arranged in such a manner, many of the coefficients at the end of the scan usually end up being zero.
15 Thus the coefficients are coded with high-efficiency. It is known that variable-length coding means that not all symbols have the same length (in bits). Huffman coding is an example of variable-length coding. Arithmetic is slightly different in that it involves a series of symbols. Thus, it is in general not possible to describe the length of ONE symbol as requiring X bits. Rather, a specific series of symbols will require Y bits. For this reason "entropy coding" is
20 perhaps a more general term than "variable-length coding".

The above-described coding scheme is used for producing a block transform of 4x4 pixels. However, Context-based Adaptive VLC (CAVLC) may involve in partitioning the transform coefficients into blocks that are larger than 4x4. For example, the JVT coder contains a feature called "Adaptive Block Transforms" (ABT) which performs transforms on
25 4x8, 8x4, and 8x8 blocks. Thus, the coding scheme designed for 4x4 blocks can no longer be applied. A solution to the problem is to split the larger block into sub-blocks of size 4x4.

An existing solution has been proposed, wherein the ABT block of coefficients is divided into 4x4 blocks in the spatial domain. As an example, an 8x8 block is shown in Figure 4 with one of the scan orders used for this block in the JVT coder. The same block
30 partitioned into four 4x4 blocks is shown in Figures 5a to 5c. Subsequently each 4x4 block is

zigzag scanned using 4x4 scan, yielding a plurality of vectors of length 16. These length 16 vectors are then passed to the standard 4x4 CAVLC algorithm. When 4x4 scan shown in Figure 1 is used for the 4x4 blocks in Figures 5a to 5c, the resulting vectors are as given in Figure 6a to 6c.

5 This existing CAVLC algorithm makes certain assumptions about the content of a coefficient vector. When these assumptions are violated, the coding tables (i.e. the tables specifying which codeword is used to describe which symbol) used by CAVLC are “mismatched”. This means that the length of codewords in the table no longer accurately reflects the probability of a symbol, and consequently CAVLC is less efficient.

10 As a result of this existing approach, each of the 4x4 blocks created after partitioning of the ABT block has coefficients corresponding to different frequencies in the ABT transform. For example, the 4x4 block of Figure 5a contains low frequency information (both horizontally and vertically) and therefore most of the high amplitude coefficients. Likewise, the 4x4 block of Figure 5d contains high frequency information and low amplitude
15 coefficients. The CAVLC algorithm assumes that higher magnitudes generally occur toward the start of the vector, and critically, it assumes that longer *runs* of zeros will generally occur toward the end of a vector. The 4x4 block of Figure 5d is statistically unlikely to contain many values in the 4x4 block of Figure 5a, and the “outlying” values are likely to have long *runs* of zeros associated with them. Although the 4x4 block of Figure 5d may contain one or
20 two nonzero coefficients, the locations of those coefficients are mismatched with what CAVLC expects, and consequently coding of that block requires a disproportionately large number of bits.

 The CAVLC method also assumes that the neighboring blocks have similar number of nonzero coefficients. For the blocks, which have coefficients corresponding to different
25 frequencies of transform functions the number of nonzero coefficients vary drastically. That can lead to the wrong choice of the VLC table used to code the number of the nonzero coefficient of a given block since this choice is based on the number of the nonzero coefficients of its neighbors.

 Thus, the existing block partitioning scheme is not an optimal solution in terms of
30 coding efficiency and quantization accuracy.

It is advantageous and desirable to provide a more efficient method and system for video and image coding, which can be applied to ABT blocks having a general size of $(4n) \times (4m)$ where n and m are positive integers equal to or greater than 1.

5 Summary of the Invention

It is a primary objective of the present invention to reduce the number of bits required to represent the quantized coefficients that result after application of a block transform larger than 4×4 . More precisely, it is aimed at reducing the number of bits required to represent coefficients resulting from a 4×8 , 8×4 , or 8×8 transform. Moreover, in order to simplify
10 design of the JVT encoder as well as to minimize the memory required by the code implementing JVT, it is desirable that the CAVLC method developed for 4×4 block is used to code 4×8 , 8×4 , or 8×8 blocks unchanged or with minimal modifications.

The objective can be achieved by partitioning a block larger than 4×4 by a plurality of sub-block of size 4×4 using the original vector in an interleaved fashion.

15 Thus, according to the first aspect of the present invention, a method of image coding characterized by

forming at least a block of transform coefficients from the image data, by
scanning the block of transform coefficients for providing a sequence of transform
coefficients, by

20 sub-sampling the transform coefficients in the sequence in an interleaved manner for providing a plurality of sub-sampled sequences of transform coefficients, and by

coding the sub-sampled sequences of transform coefficients using an entropy encoder.

Advantageously, said sub-sampling is carried out prior to or after said coding.

Preferably, the sequence of the transform coefficients has a length of $16nm$, where n
25 and m are positive integer equal to or greater than 1, and each of said sub-sampled sequence of the transform coefficients has a length of 16.

According to the second aspect of the present invention, there is provided a computer program to be used in image coding, wherein the coding process comprises the steps of:

forming at least a block of transform coefficients from the image data, and

scanning the block of transform coefficients for providing a sequence of transform coefficients. The computer program is characterized by

an algorithm for sub-sampling the transform coefficients in the sequence in an interleaved manner for providing a plurality of sub-sampled sequences of transform coefficients.

Advantageously, the coding process further comprises the step of coding the sub-sampled sequences of transform coefficients using an entropy encoder.

Alternatively, the coding process further comprises the step of coding the sequence of transform coefficients using an entropy encoder prior to said sub-sampling.

According to the third aspect of the present invention, there is provided an image encoder for receiving image data and providing a bitstream indicative of the image data. The image encoder is characterized by:

means for forming at least a block of transform coefficients from the image data, by

means for scanning the block of transform coefficients for forming an ordered

sequence of transform coefficients from the block, by

a software program for sub-sampling the ordered sequence of transform coefficients in order to form a plurality of sub-sampled sequences of transform coefficients, by

means for entropy coding the sub-sampled sequences of transform coefficients for provided signals indicative of the encoded transform coefficients, and by

means, for providing the bitstream based on the signals.

According to the fourth aspect of the present invention, there is provided an image coding system comprising a server for providing a bitstream indicative of image data and a client for reconstructing the image data based on the bitstream, wherein the server characterized by

a receiver for receiving signals indicative of the image data, by

means for forming at least a block of transform coefficients from the signals, by

means for scanning the block of transform coefficients for forming an ordered

sequence of transform coefficients from the block, by

a software program for sub-sampling the ordered sequence of transform coefficients

in order to form a plurality of sub-sampled sequences of transform coefficients, by

means for entropy coding the sub-sampled sequences of transform coefficients for provided further signals indicative of the encoded transform coefficients, and by means, for providing the bitstream based on the further signals.

5 Brief Description of the Drawings

Figure 1 is an exemplary zigzag scan for a 4x4 block.

Figure 2 is a block diagram showing a typical video server, which employs block-based transform coding and motion-compensated prediction.

10 Figure 3 is a block diagram showing a typical video client corresponding to the encoder of Figure 2.

Figure 4 is an exemplary zigzag scan for an 8x8 block.

Figure 5a is a 4x4 sub-block from the 8x8 block of Figure 4.

Figure 5b is another 4x4 sub-block from the 8x8 block of Figure 4.

Figure 5c is yet another 4x4 sub-block from the 8x8 block of Figure 4.

15 Figure 5d is the fourth 4x4 sub-block from the 8x8 block of Figure 4.

Figure 6a is a one-dimensional array representing a vector, according to the 4x4 block of Figure 5a, to be passed to the 4x4 CAVLC algorithm.

Figure 6b is a one-dimensional array representing a vector, according to the 4x4 block of Figure 5b, to be passed to the 4x4 CAVLC algorithm.

20 Figure 6c is a one-dimensional array of coefficients representing a vector, according to the 4x4 block of Figure 5c, to be passed to the 4x4 CAVLC algorithm.

Figure 6d is a one-dimensional array representing a vector, according to the 4x4 block of Figure 5d, to be passed to the 4x4 CAVLC algorithm.

25 Figure 7 is a one-dimensional vector representing an ordered sequence of coefficients of a 8x8 block.

Figure 8a is a one-dimensional array of coefficients representing the first segmented vector from the original vector, according to the present invention.

Figure 8b is a one-dimensional array of coefficients representing the second segmented vector from the original vector, according to the present invention.

Figure 8c is a one-dimensional array of coefficients representing the third segmented vector from the original vector, according to the present invention.

Figure 8d is a one-dimensional array of coefficients representing the fourth segmented vector from the original vector, according to the present invention.

5 Figure 9 is a block diagram showing an exemplary video server, according to the present invention.

Figure 10 is a block diagram showing a video client, according to the present invention, which is corresponding to the video encoder of Figure 9.

Figure 11a is a 4x4 block sub-sampled from an 8x8 block of transform coefficients.

10 Figure 11b is another 4x4 block sub-sampled from an 8x8 block of transform coefficients.

Figure 11c is yet another 4x4 block sub-sampled from an 8x8 block of transform coefficients.

15 Figure 11d is the fourth 4x4 block sub-sampled from an 8x8 block of transform coefficients.

Best Mode to Carry Out the Invention

20 The block segmentation method, according to the present invention, partitions an ABT block (an 8x8 block, a 4x8 or 8x4 block) of transform coefficients into 4x4 blocks, which are encoded using the standard 4x4 CAVLC algorithm. The division of the coefficients among 4x4 blocks is based on the coefficients energy to ensure that the statistical distributions of coefficients in each 4x4 blocks is similar. The energy of the coefficient depends on the frequency of the transform function to which it corresponds and can be for example indicated by its position in the zigzag scan of the ABT block. As a result of such

25 division, not all the coefficients selected to a given 4x4 block are adjacent to each other spatially in ABT block.

The method presented in this invention operates on blocks of coefficients produced using a 4x8, 8x4 or 8x8 transform, which have subsequently been scanned in a zigzag pattern (or any other pattern) to produce an ordered vector of coefficients.

As mentioned earlier, the goal of zigzag scanning is to pack nonzero coefficients toward the start of the coefficient vector. Effectively, the goal is to arrange the coefficients according to decreasing energy (variance). The actual scan used to accomplish this is of no consequence to this invention, provided the energy is generally decreasing.

5 After zigzag scanning to produce a length N ordered vector of coefficients (N being 64 for an 8x8 block, or 32 for a 4x8 or 8x4 block), the algorithm of the present invention segments this vector into $N/16$ smaller vectors, each of length 16. Each such vector is formed by taking every $(N/16)^{\text{th}}$ coefficient from the length N coefficient vector in a sub-sampling process. For example, if the ordered vector contains coefficients labeled $c_0, c_1, c_2, \dots, c_{63}$,
10 then the first segmented vector of length 16 contains $c_0, c_4, c_8, c_{12}, \dots, c_{60}$. The second segmented vector of length 16 vector contains $c_1, c_5, c_9, c_{13}, \dots, c_{61}$, and so on for the third and fourth vectors. For example, if the ordered vector is represented by a one-dimensional array of 64 coefficients as shown in Figure 7, then the first, second, third and fourth segmented vectors of length 16 are shown, respectively, in Figures 8a - 8d.

15 After the sub-sampled vectors of length 16 are obtained in the described manner, they are encoded using the standard 4x4 CAVLC algorithm. As written in the CAVLC description, coding of nonzero coefficients relies on the number of nonzero coefficients of the upper and left neighboring 4x4 blocks (See Figures 8a to 8d). Therefore each of the vectors created by splitting ABT block is assigned the spatial locations of one of the 4x4 blocks
20 created by dividing ABT block spatially. For example when the method of the present invention operates on 8x4 block the first vector is assigned upper 4x4 block and the second vector lower block.

In the method, according to the present invention, where every fourth coefficient is selected as shown in Figures 8a - 8d, one coefficient out of the first ("most significant") four
25 coefficients numbered 0-4 is allocated to each 4x4 block. One coefficient out of the next group of four (numbered 4-7) is allocated to each 4x4 block. The same pattern repeats for remaining groups of four coefficients. This has the effect of "balancing" the amount of energy in each of the resulting 4x4 blocks. According to our experiments, this algorithm requires an average of 3-5% fewer bits to represent a given video sequence, when compared
30 to the existing solution.

To facilitate the video coding using the vector segmentation method, according to the present invention, a video server **102** as shown in Figure 9 and a video client **202** as shown in Figure 10 can be used. The major difference between the encoder **242**, according to the present invention, and the typical encoder **40** (Figure 2) is that the multiplex encoder **242** comprises an interleaving segmentation unit **48** for segmenting an ABT block (a $4n \times 4m$ block, with n, m being positive integer equal to or greater than 1) into $n \times m$ blocks in an interleaved manner, as illustrated in Figures 8a - 8d. According to the present invention, after the scanning unit **42** produces an ordered vector of coefficients of length N ($N=16n \times m$), a computer software in the interleaving segmentation unit **48** having an algorithm is used to segment this ordered vector into $n \times m$ smaller vectors, each of which has a length of 16. Each such vector is formed by taking every $(n \times m)^{\text{th}}$ coefficients from the ordered coefficient vector of length N . Thus, the bitstream **142** is indicative of the contexts of the $n \times m$ segmented vectors.

Likewise, in the decoder **262** of the client **202** has a vector assembling unit **66**, which has a computer program with an algorithm for regrouping the coefficients in $n \times m$ segmented vectors into an ordered vector of length N .

It should be noted that the algorithm as described in conjunction with Figures 8a to 10 is a specific embodiment of a more general concept. It is possible to assign a number to each position in the length N vector representing its "distance" from the DC (or first) term in the vector. This value should reflect the relative importance of the coefficients in that position. For example, in Figure 1, the selection of whether to encode position 1 or 2 first is nearly arbitrary; therefore they might be assigned the same "distance" or "cost" value.

Ensuring that all blocks possess similar characteristics (i.e. are suited to the CAVLC coder) is then a minimization problem. For each possible allocation pattern, the total "cost" of coefficients in each 4×4 block can be calculated, and the variance across the 4×4 blocks taken. The allocation pattern that minimizes the variance will lead to blocks with the most similar statistical properties.

Mathematically, if \mathbf{P} is the set of allocation patterns, then we want to calculate the value of p such that

$$\sigma^2 = \min_{\mathbf{p}} \sigma_p^2$$

where $\sigma_p^2 = \text{var} \left\{ \sum_i^{16} d_{1,i}, \dots, \sum_i^{16} d_{N/16,i} \right\}$ and $d_{i,j}$ is the “cost” of the i^{th} coefficient in the j^{th}

segmented vector. As mentioned above, the allocation pattern described here is one example of an attempt to minimize the “cost variance” between segmented blocks. It should be understood that if the allocation patterns are selected adaptively, information on the

5 allocation pattern that is used at the encoder needs to be transmitted to the decoder. Alternatively, the allocation pattern can be determined from other parameters used in the coding of the image. What is essential here is that both the encoder and the decoder use the same allocation pattern, since otherwise the coded image cannot be decoded properly.

It should be noted that the DC coefficient can be coded differently and separately.

10 However, in order to ensure that the existing 4x4 CAVLC is unchanged, the DC coefficient is not treated any differently than the 3 lowest-frequency AC values. Treating the DC coefficient separately would mostly result in a benefit when there are very few coefficients in the block (for example, for an 8x8 block, three out of four 4x4 blocks are empty). In this case, it may be desirable to exclude the DC term from the prediction of number of non-zero

15 values. However, the benefit may not be significant in general.

The distance/cost metric intrinsic to a coefficient's position in the scan can be used to determine which 4x4 block that coefficient is allocated to. For example, a cost pattern of (0 0 0 0 1 1 1 1 2 2 2 2 3 3 3 3 ...) can be used for such determining. Alternatively, a cartesian distance such as "0111.42 ..." can be used. The effect of the allocation algorithm is to create

20 blocks with an equal or approximately equal total cost. As such, the variance of the total cost for each block is taken to be a measure of the similarity. The block selected for the next coefficient in the scan is the block with the lowest accumulated cost of coefficients allocated to it so far.

It is also possible that, prior to zigzag scanning, a pre-determined sub-sample

25 procedure is used to sub-sample the 8x8 block as shown in Figure 4 into four “interleaved” sub-blocks as shown in Figures 11a - 11d. A zigzag scan is then applied to these sub-blocks in order to produce four ordered vectors of length 16. As such, the result is equivalent to that shown in Figures 8a to 8d. Accordingly, it is possible to provide an image coding method, which comprises the steps of:

1. forming at least a block of transform coefficients for the image data;
2. sub-sampling the transform coefficients in the block in a pre-determined manner for providing a plurality of sub-sampled blocks of transform coefficients;
3. scanning the sub-sampled blocks of transform coefficients for providing a plurality
5 of sub-sampled sequences of transform coefficients, and
4. coding the sub-sampled sequences of transform coefficients using an entropy encoder.

10 The method of the present invention as described herein above divides coefficients corresponding to different frequencies of the ABT transform among 4x4 blocks more equally. Therefore the created 4x4 blocks have properties statistically similar to those expected by the CAVLC coder, which leads to increased coding efficiency.

15 Thus, although the invention has been described with respect to a preferred embodiment thereof, it will be understood by those skilled in the art that the foregoing and various other changes, omissions and deviations in the form and detail thereof may be made without departing from the scope of this invention.

What is claimed is:

1. A method of image coding using data indicative of an image, characterized by forming at least a block of transform coefficients from the image data, by
5 scanning the block of transform coefficients for providing a sequence of transform coefficients, by
sub-sampling the transform coefficients in the sequence in an interleaved manner for providing a plurality of sub-sampled sequences of transform coefficients, and by
coding the sub-sampled sequences of transform coefficients using an entropy encoder.
10
2. The method according to claim 1, characterized in that said sub-sampling is carried out prior to said coding.
3. The method according to claim 1, characterized in that said coding is carried out prior
15 to said sub-sampling.
4. The method according to any one of claims 1 to 3, characterized in that said sequence of the transform coefficients has a length of $16n \times m$, where n and m are positive integer equal to or greater than 1.
20
5. The method according to claim 4, characterized in that each of said sub-sampled sequence of the transform coefficients has a length of 16.
6. The method according to any one of claims 1 to 5, characterized in that said image
25 data is prediction error data.
7. The method according to any one of claims 1 to 5, characterized in that said image data is pixel data.

8. The method according to any one of claims 1 to 7, further characterized by quantizing the transform coefficients into quantized transform coefficients.

9. A computer program to be used in image coding image data indicative of an image,
5 wherein the coding process comprises the steps of:

forming at least a block of transform coefficients from the image data, and

scanning the block of transform coefficients for providing a sequence of transform coefficients, said computer program characterized by

an algorithm for sub-sampling the transform coefficients in the sequence in an

10 interleaved manner for providing a plurality of sub-sampled sequences of transform coefficients.

10. The computer program according to claim 9, characterized in that the coding process further comprises the step of coding the sub-sampled sequences of transform coefficients

15 using an entropy encoder.

11. The computer program according to claim 9, characterized in that the coding process further comprises the step of coding the sequence of transform coefficients using an entropy encoder prior to said sub-sampling.

12. An image encoder for receiving image data and providing a bitstream indicative of the image data, characterized by:

means for forming at least a block of transform coefficients from the image data, by

means for scanning the block of transform coefficients for forming an ordered

25 sequence of transform coefficients from the block, by

a software program for sub-sampling the ordered sequence of transform coefficients in order to form a plurality of sub-sampled sequences of transform coefficients, by

means for entropy coding the sub-sampled sequences of transform coefficients for providing signals indicative of the encoded transform coefficients, and by

30 means, for providing the bitstream based on the signals.

13. The image encoder according to claim 12, characterized in that the software program forms the plurality of sub-sampled sequences of transform coefficient prior to the entropy coding means providing the signals indicative of the encoded transform coefficients.

5 14. The image encoder according to claim 12, characterized in that the entropy coding means provides the signals indicative of the encoded transform coefficients prior to the software program forming the plurality of sub-sampled sequences of transform coefficient.

10 15. The image encoder according to any one of claims 12 to 14, characterized in that said image data is prediction error data.

16. The image encoder according to any one of claims 12 to 14, characterized in that said image data is pixel data.

15 17. An image coding system comprising a server for providing a bitstream indicative of image data and a client for reconstructing the image data based on the bitstream, wherein the server characterized by

a receiver for receiving signals indicative of the image data, by

means for forming at least a block of transform coefficients from the signals, by

20 means for scanning the block of transform coefficients for forming an ordered sequence of transform coefficients from the block, by

a software program for sub-sampling the ordered sequence of transform coefficients in order to form a plurality of sub-sampled sequences of transform coefficients, by

25 means for entropy coding the sub-sampled sequences of transform coefficients for providing further signals indicative of the encoded transform coefficients, and by

means, for providing the bitstream based on the further signals.

18. The image coding system according to claim 17, characterized in that the software program forms the plurality of sub-sampled sequences of transform coefficient prior to the entropy coding means providing the signals indicative of the encoded transform coefficients.

19. The image coding system according to claim 17, characterized in that the entropy coding means provides the signals indicative of the encoded transform coefficients prior to the software program forming the plurality of sub-sampled sequences of transform
5 coefficient.

20. The image coding system according to any one of claims 17 to 19, characterized in that said image data is prediction error data.

10 21. The image coding system according to any one of claims 17 to 19, characterized in that said image data is pixel data.

22. A method of image coding using image data indicative of an image, characterized by forming at least a block of transform coefficients from the image data, by
15 sub-sampling the transformation coefficients in the block in an interleaved manner for providing a plurality of sub-sampled blocks of transform coefficients, by scanning the sub-sampled blocks of transform coefficients for providing a plurality of sub-sampled sequences of transform coefficients, and by coding the sub-sampled sequences of transform coefficients using an entropy encoder.

20 23. A method of image coding using image data indicative of an image, wherein at least a block of transform coefficients is formed from the image data and the block of transformation coefficients is scanned for providing a sequence of transform coefficients located at a plurality of positions in the sequence, wherein the positions include a reference position so
25 that each of said plurality of positions relative to the reference position defines a distance, said method characterized by

assigning a cost value to each of the distances, by
arranging the transform coefficients in the sequence into a plurality of sub-sequences based on the cost values, and by
30 coding the sub-sequences of transform coefficients using an entropy encoder.

24. The method according to claim 23, wherein each of the sub-sequences has a total cost indicative of a sum of the cost values associated with the transform coefficients in said each sub-sequence, said method characterized in that

5 said arranging is adapted to achieve a minimum in the difference between the total cost of said each sub-sequences and the total cost of each of the other sub-sequences.

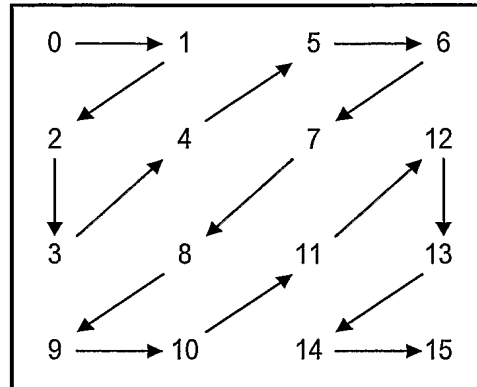


FIG. 1

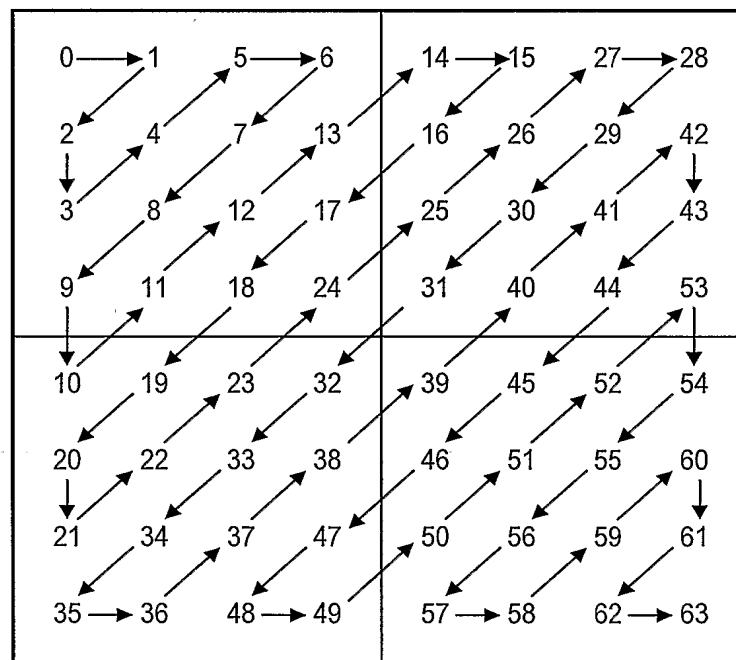


FIG. 4

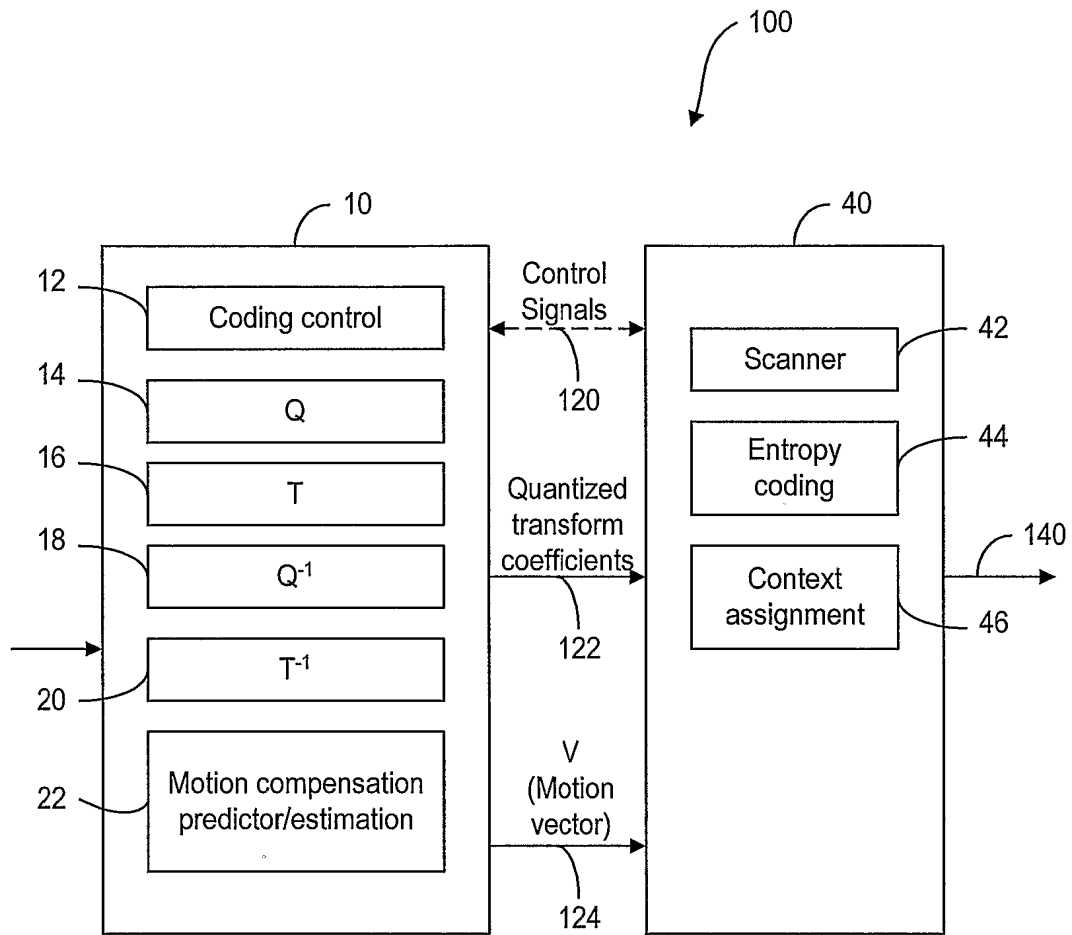


FIG. 2

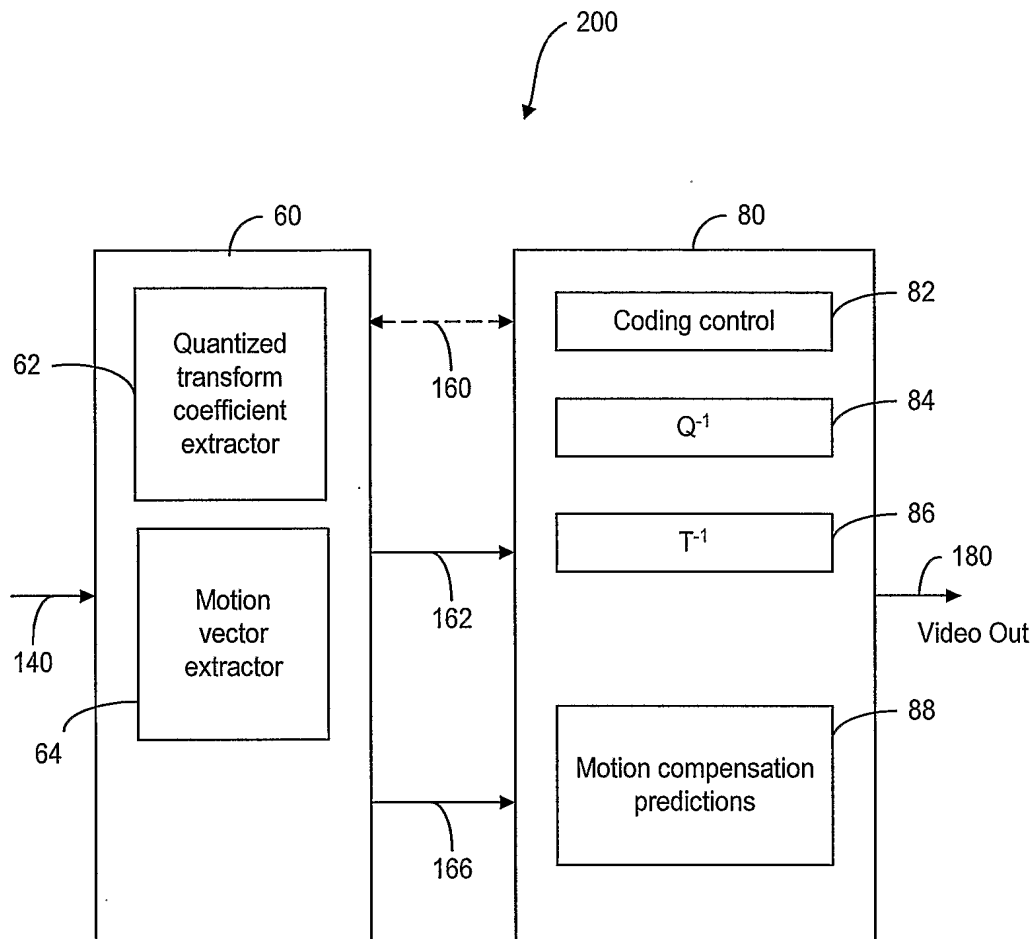


FIG. 3

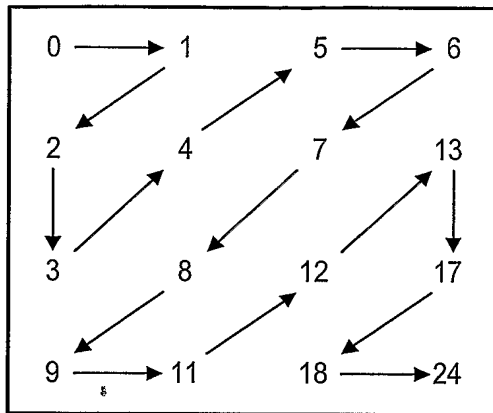


FIG. 5a

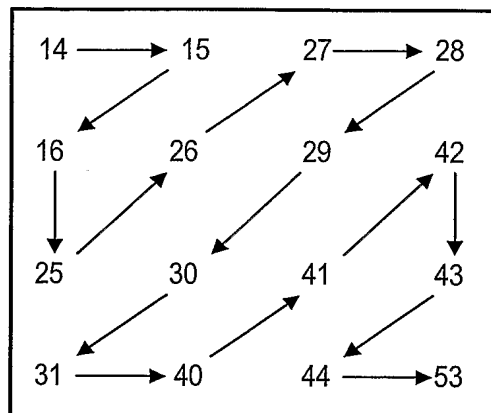


FIG. 5b

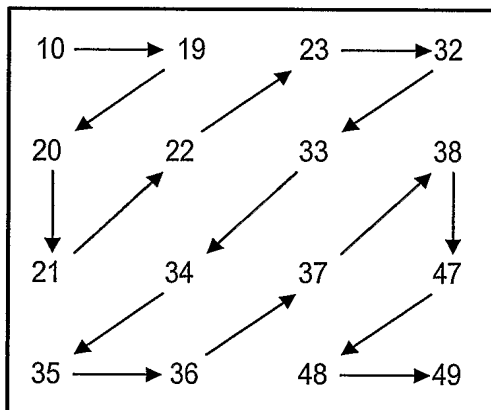


FIG. 5c

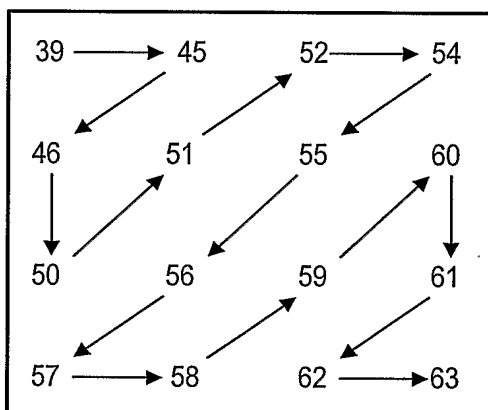


FIG. 5d

FIG. 6a

0	1	2	3	4	5	6	7	8	9	11	12	13	17	18	24
---	---	---	---	---	---	---	---	---	---	----	----	----	----	----	----

FIG. 6b

14	15	16	25	26	27	28	29	30	31	40	41	42	43	44	53
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

FIG. 6c

10	19	20	21	22	23	32	33	34	35	36	37	38	47	48	49
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

FIG. 6d

39	45	46	50	51	52	54	55	56	57	58	59	60	61	62	63
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

FIG. 7

0	1	2	3	4	5	6	7	• • •	58	59	60	61	62	63
---	---	---	---	---	---	---	---	-------	----	----	----	----	----	----

FIG. 8a

0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60
---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----

FIG. 8b

1	5	9	13	17	21	25	29	33	37	41	45	49	53	57	61
---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----

FIG. 8c

2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	62
---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----

FIG. 8d

3	7	11	15	19	23	27	31	35	39	43	47	51	55	59	63
---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----

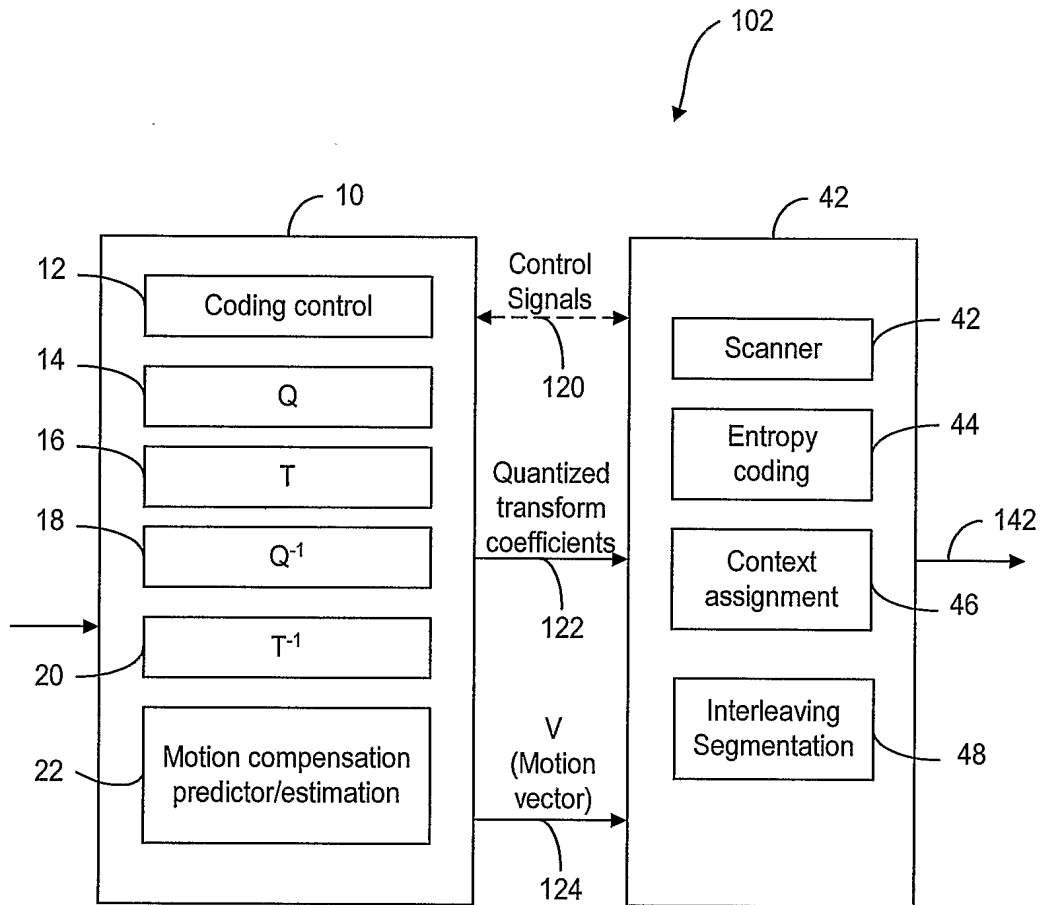


FIG. 9

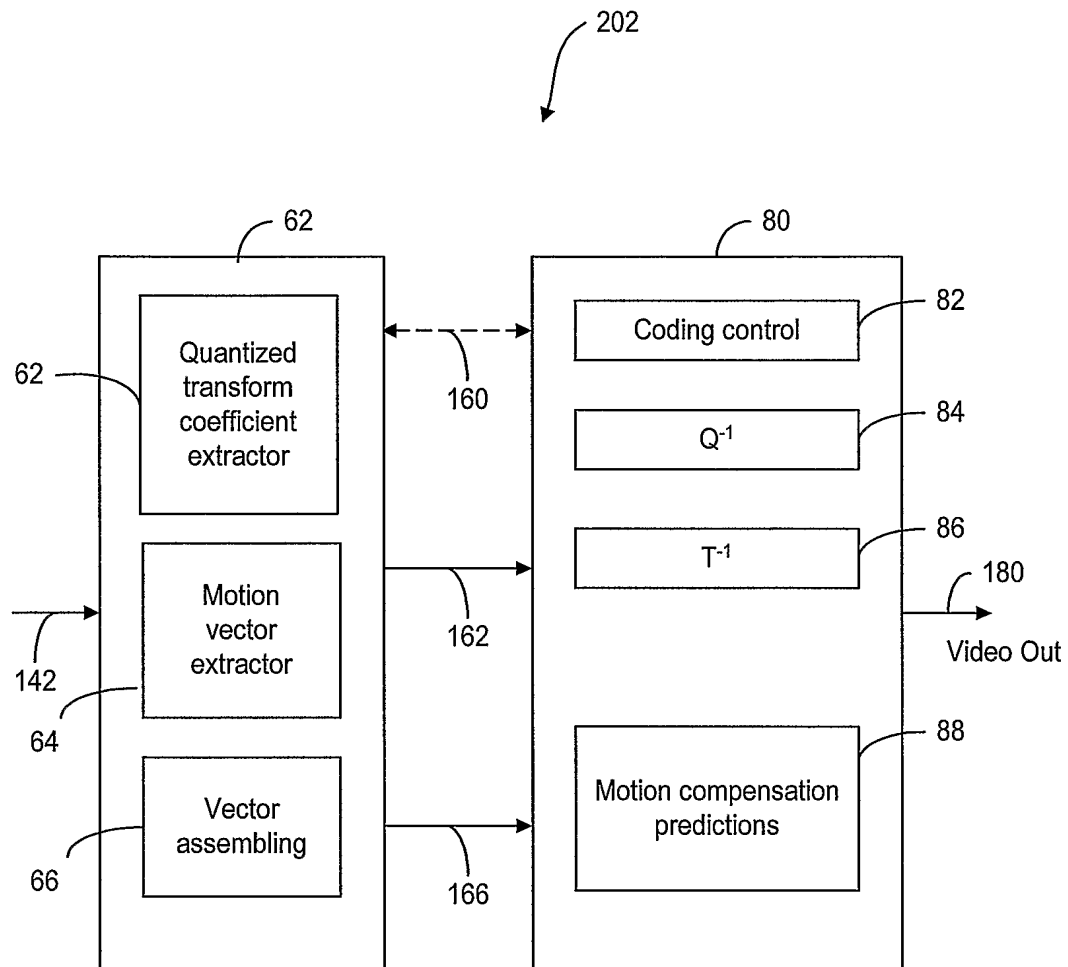


FIG. 10

FIG. 11b

1	5	9	13
17	21	25	29
33	37	41	45
49	53	57	61

FIG. 11d

3	7	11	15
19	23	27	31
35	39	43	47
51	55	59	63

FIG. 11a

0	4	8	12
16	20	24	28
32	36	40	44
48	52	56	60

FIG. 11c

2	6	10	14
18	22	26	30
34	38	42	46
50	54	58	62

INTERNATIONAL SEARCH REPORT

International application No.

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A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G06K 9/46

US CL : 382/239

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 382/236,238,239; 341/50,51; 348/404,406,407,419; 358/426.02,426.05; 704/270.1; 375/240.27

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
IEEE Database, East database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	MARPE, et al. Video compression using context based adaptive arithmetic coding, IEEE 2001 publication pages 558-561, the entire document	1-24
Y,P	US 2003/0012286 A1 (ISHTIAQ et al) 16 January 2003, see 0026, 0028, figure 2	1-24
Y,P	US 6,577,251 (YIP) 10 June 2003, entire document.	1-24

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☐ See patent family annex.

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